AFFDL-TR-69-123
VOLUME III

AD706374

A STABILITY AND CONTROL PREDICTION METHOD FOR HELICOPTERS AND STOPPABLE ROTOR AIRCRAFT

VOLUME III
PROGRAMMER'S MANUAL

BILLY J. BIRD

Bell Helicopter Company
A Textron Company

TECHNICAL REPORT AFFDL-TR-69-123, VOLUME III

MARCH 1970

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200 - April 1970 - CO455 - 117-2581

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FOREWORD

This report represents the results of the efforts expended in performance of Contract F33615-69-C-1121, "Development of Stability and Control Prediction Methods for Stoppable Rotor Aircraft." The work was performed by Bell Helicopter Company under Project No. 8219. It was sponsored by the Air Force Flight Dynamics Laboratory, Air Force Systems Command, from December 1968 through February 1970. Mr. Charles L. Livingston was the Bell Helicopter Company Project Engineer. Mr. Robert Nicholson was the Air Force Project Engineer.

This final report is presented in four volumes. The first describes the mathematical model and the methods used to calculate stability characteristics. They are of sufficient complexity that a digital computer is necessary for the solution of the equations. The second volume presents the results of sample computations and discusses input and output formats and good user techniques. The third volume describes the computer program while the fourth volume contains Appendices which are computer generated documentation of the program.

The author gratefully acknowledges the assistance of Messrs. B. L. Blankenship and Tyce McLarty of the Bell Helicopter Company Aeromechanics Group and Mr. C. L. Livingston of the Stability and Control Group in the development of the mathematical model.

This technical report has been reviewed and is approved.

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ABSTRACT

This report describes a mathematical model of rotorcraft that may be used to determine characteristics of performance, stability, response, and rotor blade loads. The complexity of the equations used requires the use of a digital computer for efficient solution. This four volume report describes the computer program in detail and illustrates the method of computing rotorcraft characteristics by specific example.

This volume contains aids for the computer programmer. The first and second volumes contain a discussion of the mathematical model and detailed instructions for the users of the program. The fourth volume contains computer generated documentation of the program.

The programming aids are divided into two groups: background material for the programmer just starting to work on this computer program and the detailed explanation of the computer generated documentation which is necessary for any programmer to work effectively on this program.

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SECTION I

INTRODUCTION

The purpose of this manual is to provide the information required to modify the computer program. The assumption is made that the reader of this volume will have first read Volumes I and II. No effort was made to make this volume self-contained because efficient and effective programming of ASAJ01 requires knowing how to use the program and knowing something of the engineering and analysis involved, as well as a knowledge of FORTRAN programming techniques.

The information in this volume is of two types, general and specific. The general information is discursive, providing background and perspective. The detailed information is that which any programmer must have at hand when making additions or modifications and when debugging these additions or modifications.

SECTION II

GENERAL PROGRAMMING AIDS

A. MACRO FLOW CHARTS

The flow charts in Figures 1 through 4 describe the functional structure of the program without regard to flow by subroutine. Figure 1 shows the total program structure and is a composite of Figures 1 through 10 in Volume II. Figure 2 provides some detail of the trim process in Figure 1. Figures 3 and 4 similarly amplify the stability analysis and maneuver functions, respectively, in Figure 1. Information which is normally presented in more detailed flow charts is, for the most part, provided in Table I and Appendices A through E, Volume IV. This table and these appendices also contain vital information which is not found in detailed flow charts.

B. FORTRAN SUBROUTINES

The FORTRAN subroutines contained in ASAJ01 are listed in alphabetical order, except for the main program, C81, which is first. A few remarks are made for each subroutine which indicates its general purpose or use in the general structure of the program. Great detail of explanation is not attempted here since it would be redundant. In the case of multiple entry subroutines, the names of all the entries will be given in the order that they occur in the subroutine. The first entry has the same name as the control section which appears in Table I.

1. C81. This routine is the main program of ASAJ01. This subprogram reads the control cards which direct the flow of the whole problem. The path is selected and calls initiated to begin working the problem. Upon return, possible errors are checked for and appropriate action is taken. If an error is detected, an error message may be printed out. Then the program either terminates execution or starts the next problem, with the severity of the error determining which.

2. AJACOB. This subroutine handles computation of quantities which depend upon variables which are changed in either subroutine TRIM or subroutine STAB, which are used in the calculation of partial derivatives. These quantities are then calculated and used then in the computation of forces and moments.

3. ANAL. Output of this subroutine consists of forces and moments from each surface or mechanism which produces either a force or a moment and the total summation of forces and moments. In the subroutine itself are calculated the forces and moments

of the wing, elevator, fin, and fuselage as well as jet thrust. The first subroutine in the rotor analysis is called and returns the rotor forces and moments.

4. CATS. The inputs to this subroutine are two sets of Euler angles and a direction number for each set. The output is a set of Euler angles which are related to the two sets input. The two sets input are the Euler angles connecting three different coordinate systems X, Y, and Z with set one connecting coordinate systems X and Y and set two connecting coordinate systems Y and Z. The output set of Euler angles connect coordinate systems X and Z. It is possible by manipulation of the direction numbers in the input and the order in which they are input to get the output set of Euler angles to be in either direction desired.

5. CLCD. The inputs to this subroutine are the angle of attack and Mach number, as well as the aerodynamic description of any airfoil. The output is the coefficient of lift and the coefficient of drag.

6. COMSOL. This subroutine solves systems of linear equations in complex variables.

7. CON1. The function of this subroutine is to take the input control group and initialize and calculate quantities which are then used in the computation of the settings of the swashplate from the control position.

8. CON2. This subroutine has a similar function to CON1 but is more specialized. The quantities which are initialized in this subroutine are confined to control phasing and secondary linking of the controls.

9. CURVET. This subroutine analyzes the time history of selected variables during a maneuver. This analysis is accomplished by a least squares curve fit followed by comparison of both the amplitude and phase angle of different variables. Then one variable is expressed as a linear function of two others.

10. C81L. The function of this subroutine is the transfer to a disk of maneuver time history data which has been stored on a tape or the transfer to a tape of maneuver time history data which has been stored on a disk.

11. DAMPER. This is the variable damper for TRIM. The purpose of this is to gradually dampen out oscillations of the trim iterations. This is accomplished by checking the errors generated in TRIM against an upper limit and, whenever all errors are less than this limit, reducing both the partial

derivative increment and the maximum amount which one of the TRIM variables can change in one iteration.

12. DAT. This is a block data subroutine which contains the alphameric data for subroutine PARA and the alphameric data for subroutines PPLOT and CURVET.

13. DAT1. This is a second block data subroutine which contains primarily C_L and C_D tables for the rotors. Other secondary data tables are included but they are of minor importance.

14. DET. In this subroutine is calculated the value of the determinant during the extraction of eigenvalues for a stability analysis.

15. DISK. This prints out the gust velocity distribution over the rotor disk during a maneuver. No printout is made if the velocity is uniform over all of the rotor disk or if none of the velocities are greater than .5 ft/sec.

16. DOGS. The inputs to this subroutine are two vectors. The output is the cross product.

17. DOROT. This subroutine is the one which performs the integration out the blade and around the azimuth during the rotor analysis. During a maneuver this integration around the azimuth is simply a summation of the quantities produced for each blade. During trim it is, however, a true integration quasi-statically around the entire azimuth.

18. ELEC. This subroutine calculates time constants, damping factors, and gains during a stability analysis.

19. GUST. This subroutine is entered only during a maneuver in which a gust is being generated. It calculates the distance of each part of the rotorcraft from the start of the gust and then calculates from that distance the magnitude of the gust velocity at each point on the ship.

20. INIT. Output is the sole function of this subroutine. It prints out the full page of the maneuver time history data. It also writes out on disk the same variables.

21. INRO. The function of this subroutine is the initialization and calculation of problem constants from the rotor inputs only.

22. ITRIM. Included in this subroutine is the iteration loop of the trim section of the program. The function here is to iterate to a stable-flight condition.

23. ITROT. This subroutine initializes variables for subroutine DOROT and, when specified by the input parameters, activates the iteration loops to balance the rotor flapping moments.

24. IVAR. This subroutine handles the initialization of the maneuver inputs for subroutine VARI.

25. JACOBI. As the name of this subroutine implies, its function is to calculate the Jacobian for use in the Newton-Raphson iteration method in TRIM or for calculating the displacement derivatives for use in the stability analysis.

26. LAMODE. This subroutine calculates the characteristic coefficient matrix for the lateral mode of the stability analysis.

27. LMODE. This subroutine calculates the characteristic coefficient matrix for the longitudinal mode of the stability analysis.

28. MANU. This subroutine controls the time variant maneuver segment. It handles the integration of the differential equations and the calling of the other subroutines necessary to a maneuver.

29. MATRIX. The function of this subroutine is to calculate the transformation matrix from a set of input Euler angles and return the proper matrix to either subroutine CATS or subroutine RATS.

30. MICE. This subroutine is a two dimensional version of subroutine RATS which rotates a vector with two components through an angle.

31. MNEM. The function of this subroutine is to calculate problem constants from input data and to initialize for a problem.

32. MODE. This subroutine controls the section for calculating the response of a rotorcraft to a given control input during the stability analysis.

33. NDSLOT. The input to this subroutine is the dimensionalized characteristic coefficient matrix in the stability analysis. The output is the nondimensional characteristic coefficient matrix.

34. NOPSIO, NOPSI1. The inputs to this subroutine are the number of azimuth stations for use in the rotor analysis. The

outputs are quantities which are a function of the number of azimuth stations.

35. OFFTRM. The outputs of this subroutine are the values to which the forces and moments on the fuselage and the rotors must be driven in order to achieve a trim condition in either a push-over, a pull-up, or a banked turn.

36. PARA. This subroutine is for output only. It prints the trim parameter summary which comes at the end of the trim.

37. PCG. As the name implies this subroutine is the prop-rotor collective governor.

38. PDZ1, PDZ. The inputs of this subroutine are a trim partial derivative matrix, that is the Jacobian, and the type of helicopter or rotorcraft being flown. This subroutine then changes the partial derivative matrix to conditions which are known to hold. Essentially, this is a crude attempt to filter numerical "noise" in the matrix.

39. PPLOT. This is the printer plot routine which produces plots of time histories of the variables calculated during a maneuver.

40. RATI. Inputs to this subroutine are the corrections to the trim variables and the maximum allowable correction. The subroutine then checks to see that no correction applied exceeds the maximum and makes proper dimensional adjustments to the corrections and then makes the corrections.

41. RATS. Inputs to this subroutine are the three components of a vector in one coordinate system and three Euler angles and a direction number of the Euler angles. The output is the three components of a vector in the other coordinate system.

42. READIN. As the name implies this subroutine reads in the input data for a problem.

43. ROOA, ROOB. This subroutine is used in the determination of the eigenvalues of the characteristic coefficient matrix in the stability analysis section of the program.

44. ROTAN. This subroutine may be considered to be the outer section of the rotor analysis.

45. SETE. This subroutine saves values of the forces and moments calculated at the end of trim or at the start of the stability analysis section for later use in comparison and in calculation of derivatives.

46. SLTE. In the part of the stability analysis concerned with the response of the rotorcraft to a step input from one of the controls, this subroutine puts the derivative with respect to the appropriate control in the proper position in the characteristic coefficient matrix.

47. SLTT. After the roots to the characteristic coefficient matrix have been calculated as a result of a modification by SLTE, this subroutine then restores the characteristic coefficient matrix to its original form.

48. SOLVE. This subroutine solves systems of linear equations by Gaussian elimination.

49. SRT. This subroutine might be considered as the driver for the finding of the roots of the characteristic coefficient matrix in the stability analysis section.

50. STAB. This subroutine is the primary subroutine in the stability analysis section and it generates or it does the calling for such quantities as the Jacobian, the rate derivatives, and the subroutines which then do the lateral and longitudinal modes analysis.

51. START. The function of this subroutine is to change units of the input arrays and set them equal to mnemonics.

52. SWAS1, SWAS. This subroutine performs the function of linking the control to the swashplates with the appropriate linkage factors and phase factors.

53. TABINT. As the name implies, this subroutine does a table interpolation for C_L or C_D in the rotor analysis.

54. TILT1, TILT, HSAF, TFFA. This subroutine handles CG shift for several different manners of shifting CG. The primary function is in a mast tilt maneuver. It provides not only for CG shift but also for changes in control phasing as a function of the mast tilt angle. Secondary entries handle CG shift with folding of a rotor either when it is being folded aft after being tilted forward and stopped or being folded horizontally after a stop.

55. TINIT. This subroutine should be considered as a subsidiary of subroutine MNEM.

56. TRIM. As the name implies, this subroutine is the primary one of the section of the program for finding the stable flight condition.

57. TURN. This subroutine handles a banked turn. Secondarily, it handles push-overs or pull-ups. It does so by checking input data, picking up proper inputs, and doing the approrpiate initialization to get started finding a stable flight condition.

58. VARI. Produced by this subroutine are the effects of the disturbances during a time variant maneuver. The inputs to this subroutine are the user supplied forcing functions and the results produced from those are the output of this subroutine.

59. VIND. This subroutine calculates the induced velocity of a rotor.

60. WAG1, WAG. A study of aerodynamics as started by Wagner and Küssner and developed by Buettiker for helicopter applications are handled in this subroutine.

61. WRFM. This is an output subroutine which writes out the rotor force and moment summary in shaft reference and the fuselage reference force and moment summary.

62. WROT1, WROT. This is another output subroutine which produces the heading for the printout of the input data, the trim page, and the printer plots.

63. WRVP1, WRVP. This is still another output subroutine which produces the printouts of the partial derivative matrices calculated and the independent variables used in the calculation of those derivatives.

64. YFIX. This subroutine takes the aerodynamic inputs, initializes and changes the dimensions on them and calculates constants for subroutine CLCD.

C. ASSEMBLY LANGUAGE SUBPROGRAMS

Besides the usual group of software routines furnished by the computer manufacturer and used by numerous programs, ASAJ01 uses three locally written general purpose subprograms. Since they are even more hardware dependent than the FORTRAN subroutines, they are included here only to give a brief description of how they are used by ASAJ01.

The first subroutine, ABDUMP, produces a dump and an abnormal termination of job when it is called. This routine is called by subroutine C81 only.

Subroutine DATE has three entries. They are DATE, SETIME, and TIMEX. The first entry, DATE, returns, as an argument in the calling sequence, the current date; that is, the date on

which the call is executed, in eight characters of alpha. The second entry SETIME has an input only. This initializes a timer for later use by the third entry TIMEX which has three arguments in the calling sequence. The first argument is the amount of time used since the beginning of the job step. The second argument is the amount of time that has elapsed since the last call to TIMEX. The third entry in the calling sequence has as its value the time left; that is, the number which was input at entry SETIME minus the first argument in TIMEX.

Function DOTX is the third subprogram. It is basically a vector dot product. The first input argument is the first element of the first vector. The second argument is the spacing between consecutive elements of the first argument which are to be used in the dot product. The third argument is the first element of the second vector to be used in the dot product. The fourth argument is the spacing between elements of the third argument. The fifth argument is how many elements are in the dot product. The effect of the second and fourth arguments is to make the routine general enough that tensors of any order may be used as the first and third arguments. The major purpose of the function is to accomplish double precision accumulation of products of single precision vectors in minimum time.

SECTION III

DETAILED PROGRAMMING AIDS

A. CONTROL SECTION CROSS-REFERENCE

The information contained in Table I is necessary and sufficient for the construction of the overlay scheme for ASAJ01. The first column contains the names of the subroutines in alphabetical order, except for the main program, C81, which is first. The second column, length, contains the size, in bytes in hexadecimal number base, of the compiled or assembled subprogram. The FORTRAN subroutines were compiled on the O/S 360 FORTRAN IV (H) Compiler with OPT=2. The third column contains several operations and the fourth column, in the same and following lines, if any, contains the names of the subroutines associated with that operation. Subroutine SLTE is a good example. The calling chain which contains SLTE is: C81 calls STAB, STAB calls LAMODE or LMODE, LAMODE or LMODE calls MODE, MODE calls SLTE, SLTE calls SRT, and SRT calls DET or ROOA. With this sequence of calls in mind, the operation "Called By" refers to MODE; "Calls" refers to SRT; "IS Used By" refers to C81, LAMODE, LMODE, and STAB; "Uses" refers to DET and ROOA.

It should be noted that, for subroutine AJACOB, there is the peculiarity that subroutine ITRIM appears for both "Called By," and "Is Used By." This means that subroutine AJACOB is called by ITRIM which also calls JACOBI which then calls AJACOB.

B. DEFINITION OF VARIABLES IN COMMON

Appendix A, which is a dictionary of the variables in common, is for use in conjunction with Appendices B through F. In the format given, the variables are first sorted by length, one-letter variables first, two-letter next and so on. Within a group of equal length, the variables are then sorted into alphabetical order. Since it is possible to have a number in a variable name, numbers follow the letter Z.

Note that in some places the variable definition begins with a number in parentheses or a group of numbers separated by commas, all within parentheses. This means that the variable is an array and its size is given. Any array that has a subscript with a maximum value of "2" is a rotor variable. The variable with the subscript one, for example B(1), refers to the first rotor, and the variable with the subscript two, for example B(2), refers to the second rotor.

Sometimes, one of these variables, which is dimensioned two, is defined by two more variables. Again, B is a good example. Variables are usually easily recognizable in the cases where one variable is defined in terms of another. It is always easy to check if some set of letters or a word is a variable by referring to the proper place in Appendix A. Local variables are not defined because it is assumed that a local variable may have its meaning deduced from how its value is calculated.

C. CROSS-REFERENCE OF VARIABLES IN COMMON

ASAJ01 is a program with a large number of subroutines and a large number of variables. The nature and order of the computations in this program are, in general, such that they prevent ready modularization below the level exhibited in Figure 1. These characteristics of ASAJ01 make cross-referencing of its variables necessary. The contents of Appendices B through E are designed to supplement a compiler which has a cross-reference option. Such a compiler provides the necessary information about the location of the usage of variables within a subroutine, while the appendices provide analogous inter-subroutine information. Appendix B is a digest of information extracted from the compiler.

Appearing at the top of each page of Appendix B are column headings of subroutine names. Immediately below the subroutine names and in the left column appear the names of the labeled Commons. Next are all of the variables arranged by the same scheme used in Appendix A. The Common which contains that variable is in the next to the last column on the right and a sequence number is given in the right column. An "X" in the middle of a line denotes that the variable whose name appears in the left column on that line is used in that subroutine. Variables which are in a subroutine only because the Common that they are in is in the subroutine are not noted. Only those variables which are used in the subroutine are entered in the tables.

As an example of reading and using Appendix B, find the line for the variable AP in the left column. Across on that line is an "X" under the column headed by "MNEM." This means that the variable AP is used in an equation or calling sequence in subroutine MNEM. Similarly noted is the usage of AP in subroutines ANAL and INIT. The next to last column on the right contains the name of the labeled common, MANAL, which contains AP. The line for MANAL indicates that AP is available for use in subroutine START but not available in subroutine READIN. Since this latter information is easily accessible in the compiler cross-reference, no particular effort was made to develop a cross-reference to enhance it.

Note that some variables are preceded by an asterisk. An example is B. Referring to Appendix A, the variable B is defined as two other variables, BM and BTR. In Appendix B, entries are made for both BM and BTR in all the subroutines for which there are entries for B.

This means that in the subroutines which have an entry for B, the variables BM and BTR are replaced in the Common by B.

The most common uses of Appendix B are checking the usage of a variable during program modification and debugging.

Appendix C is a list of variables and Commons appearing in a subroutine. The subroutine name heads the list, followed by the names of the labeled Commons appearing in this subroutine, followed by the names of the variables used in the same order as they appear in the left column of Appendix B. The subroutines are listed in order of appearance in the page headings of Appendix B reading from left to right. After the subroutine listings come similar listings for each of the Commons. That is a Common name followed by the names of the variables which are in that Common. Again the order is the same as in the left column of Appendix B. The order given here is not necessarily the same as the order that the variables appear in the FORTRAN listing in Appendix F.

One page of Appendix C is derived from Appendix B by selecting a column, printing the subroutine name, heading that column, and then searching down the column for an "X." When an "X" is encountered on some line, print the variable name that is on that line in the left column.

Appendix C is primarily used to check the contents of Appendix B with the compiler and thus assure the accuracy of Appendix B.

Appendix D is Appendix B grouped by Common and is used to decide whether to put a Common in a subroutine or to put the needed variables in the calling sequence. This decision is made after considering the number of variables needed, the frequency of changing the Common and thus recompiling the subroutine.

Appendix E is derived from Appendix D by combining subroutines into sections. The column headings of Appendix E are the names of the subroutines which control their section. The first section, C81, contains only subroutine C81. The second section, START, contains subroutines START through VIND (reading across the headings of Appendix D) and TILT and IVAR; section ROTAN contains subroutines VIND through DOROT; section ANAL contains subroutines ANAL through SWAS; section

MANU contains subroutines MANU through WRFM; section STAB contains subroutines WRFM through WRVP; section TRIM contains subroutines JACOBI through IVAR; section PPLOT contains subroutines PPLOT through CURVET.

Appendix E is used to group the variables for the labeled Commons.

D. FORTRAN LISTING

The FORTRAN subroutines are listed in Appendix F in alphabetical order except for the main program, C81, which is first.

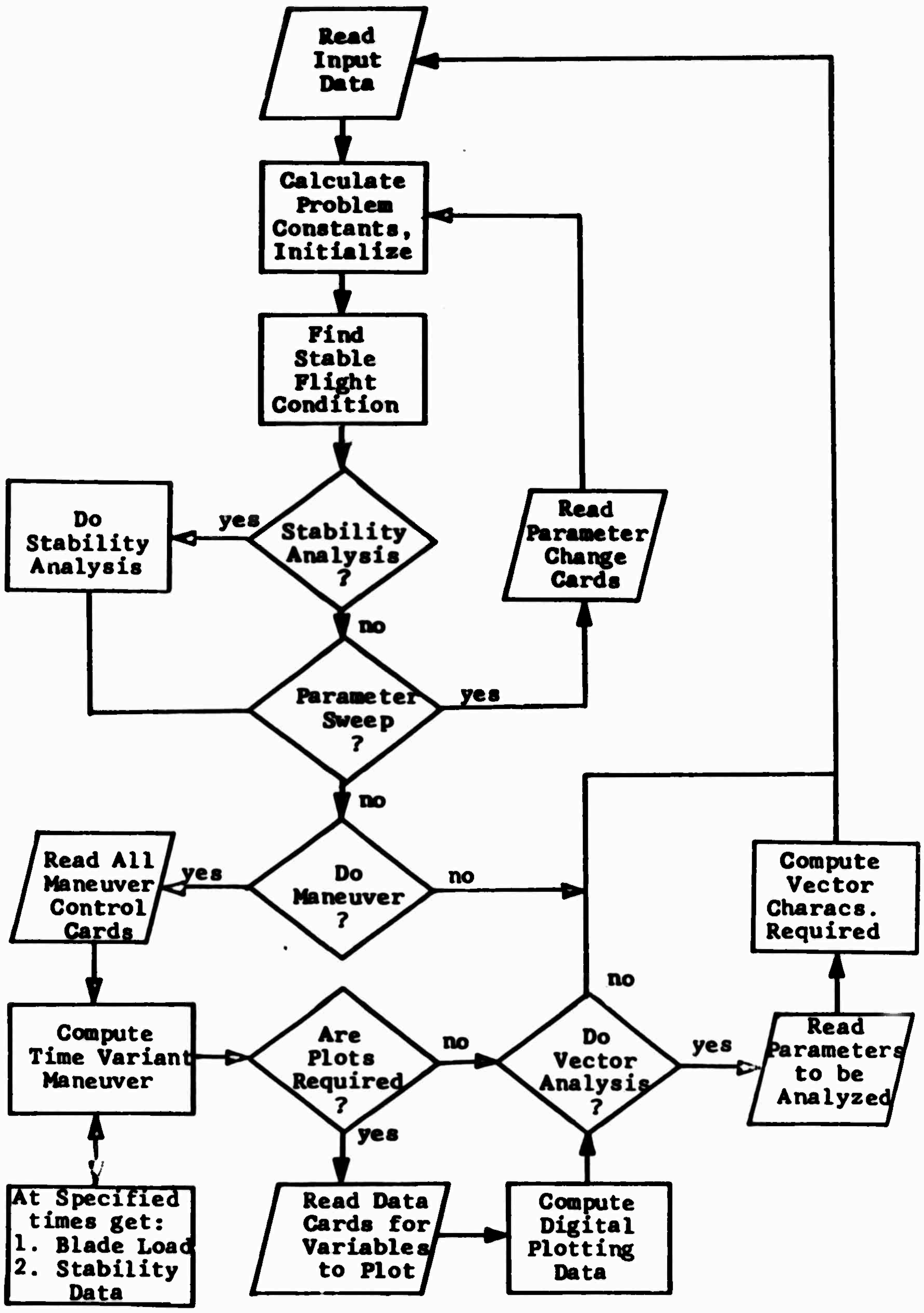

Figure 1. Flow Chart of Program Structure

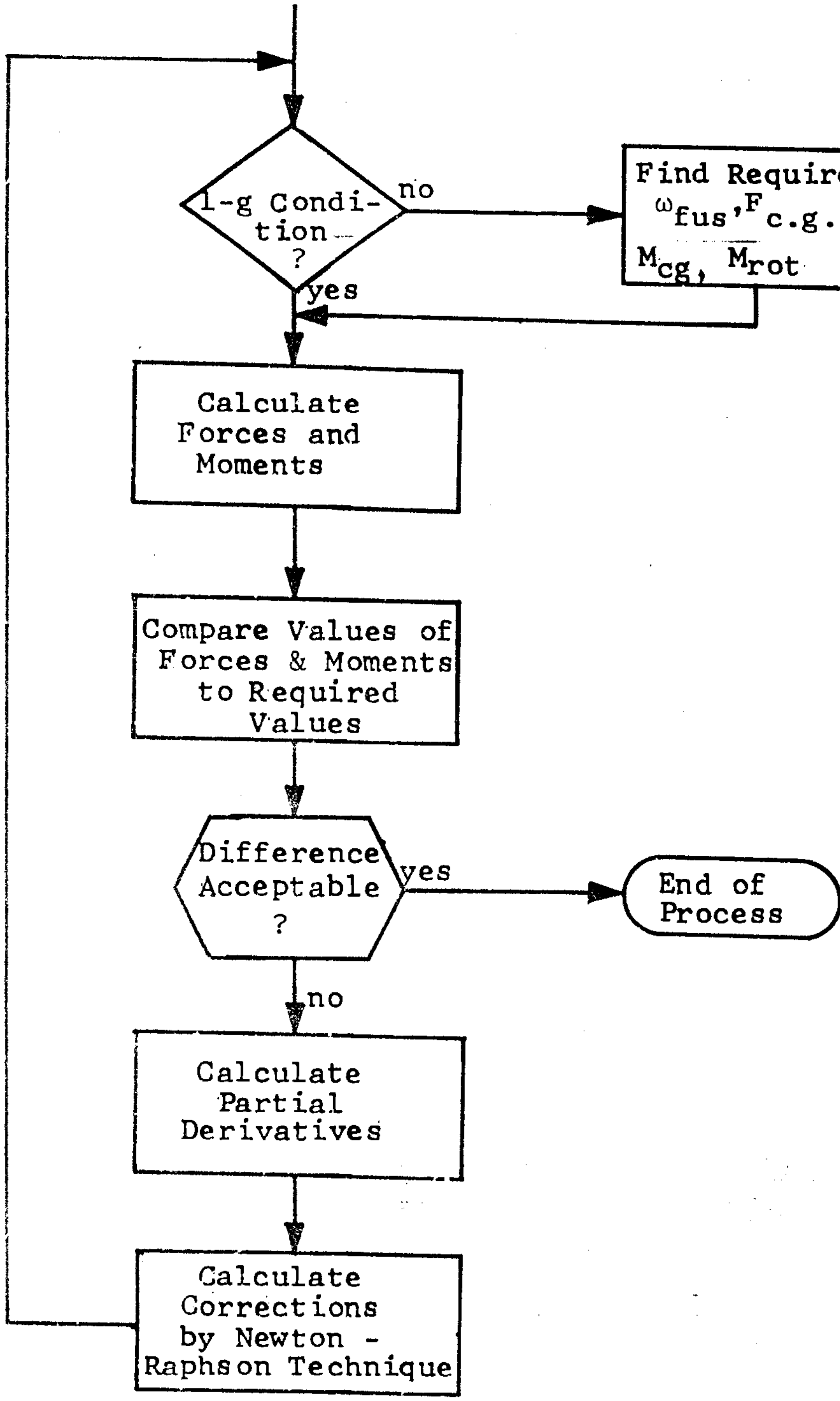

Figure 2. Flow Chart of Trim Process

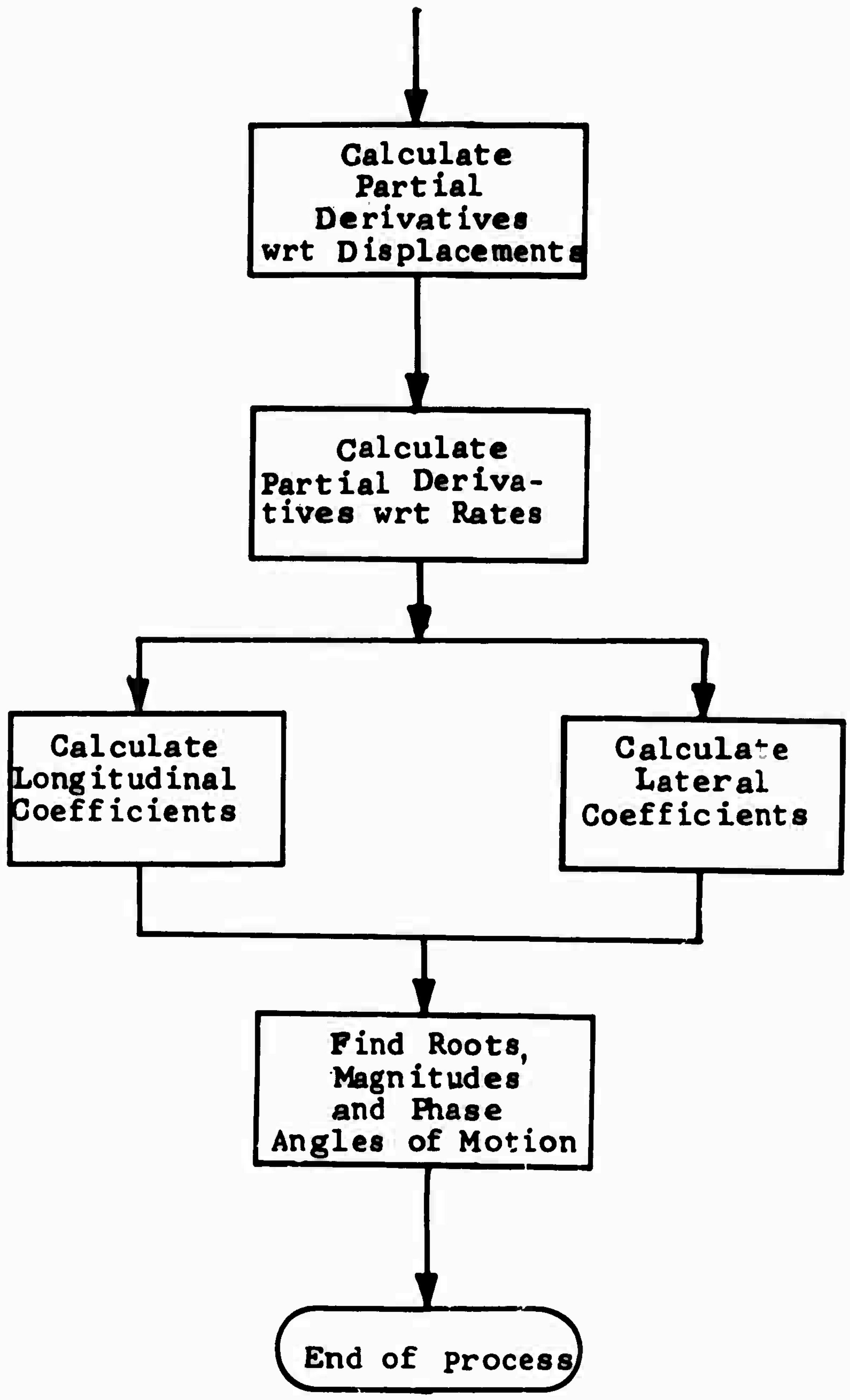

Figure 3. Flow Chart of Stability Analysis

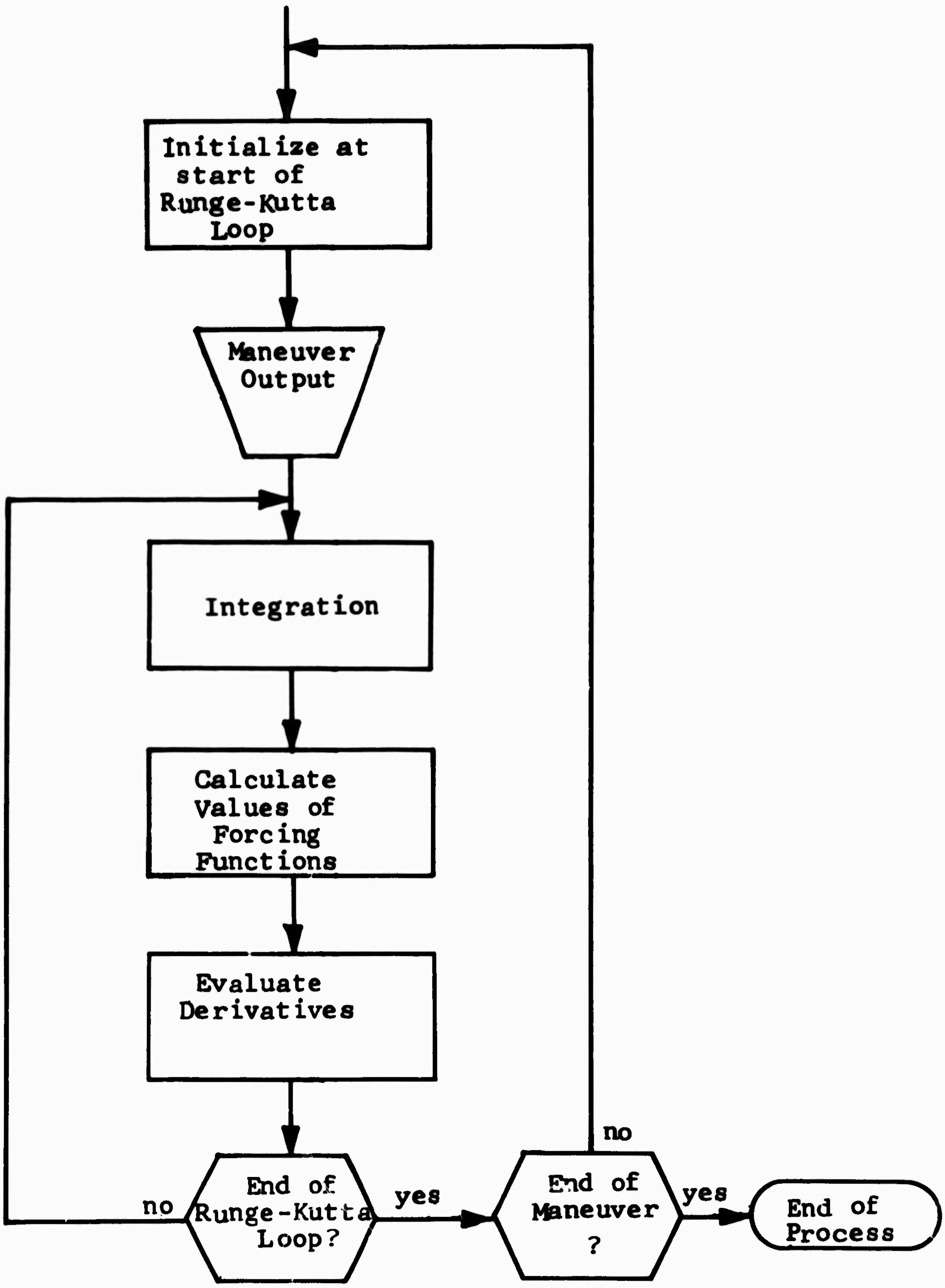

Figure 4. Flow Chart of Maneuver

TABLE I. CONTROL SECTION CROSS-REFERENCE

Name	Length	Operation	Cross-Reference			
C81	COO	Calls	ABDUMP	CURVET	DATE	MANU
			PPLOT	STAB	START	TRIM
			WROT1			
		Uses	AJACOB	ANAL	CATS	CLCD
			COMSOL	CON1	CON2	C81L
			DAMPER	DATE	DET	DISK
			DOGS	DOROT	DOTX	ELEC
			GUST	INIT	INRO	ITRIM
			ITROT	IVAR	JACOBI	LAMODE
			LMODE	MATRIX	MICE	MNEM
			MODE	NDSLOT	NOPSIO	OFFTRM
			PARA	PCG	PDZ1	RATI
			RATS	READIN	ROOA	ROTAN
			SETE	SLTE	SLTT	SOLVE
			SRT	SWAS1	TABINT	TILT1
			TINIT	TURN	VARI	VIND
			WAG1	WRFM	WROT1	WRVP1
			YFIX			
ABDUMP	20	Called By	C81			
AJACOB	390	Called By	ITRIM	JACOBI	STAB	
		Is Used By	C81	ITRIM	STAB	TRIM
		Calls	ANAL	OFFTRM	RATS	SWAS1
			WRFM	WRVP1		
		Uses	CATS	CLCD	DISK	DOGS
			DOROT	DOTX	ITROT	MATRIX
			MICE	RATS	ROTAN	TABINT
			VIND	WAG1		
ANAL	1578	Called By	AJACOB	MANU	STAB	
		Is Used By	C81	ITRIM	JACOBI	STAB
			TRIM			
		Calls	CLCD	DOGS	MICE	RATS
			ROTAN	WAG1		
		Uses	CATS	CLCD	DISK	DOGS
			DOROT	DOTX	ITROT	MATRIX
			MICE	RATS	TABINT	VIND
			WAG1			

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
CATS	5D8	Called By	OFFTRM	ROTAN		
		Is Used By	C81	AJACOB	ANAL	ITRIM
			JACOBI	MANU	STAB	TRIM
		Calls	MATRIX			
CLCD	CD8	Called By	ANAL	DOROT	MNEM	
		Is Used By	C81	AJACOB	ANAL	ITRIM
			ITROT	JACOBI	MANU	ROTAN
			STAB	START	TRIM	
		Calls	MICE	TABINT		
COMSOL	738	Called By	LAMODE	LMODE		
		Is Used By	C81	STAB		
CON1	488	Called By	START			
		Is Used By	C81			
CON2	2E8	Called By	MNEM			
		Is Used By	C81	START		
CURVET	4EB8	Called By	C81			
		Calls	DATE	WROT1		
		Uses	DATE			
C81L	8F0	Called By	PPLOT			
		Is Used By	C81			
		Calls	DATE			
DAMPER	138	Called By	ITRIM	TRIM		
		Is Used By	C81	TRIM		

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
DATE	1F0	Called By	C81 ITRIM WROT1	CURVET PARA	C81L PPLOT	INIT STAB
		Is Used By	C81 PARA	CURVET PPLOT	ITRIM START	MANU TRIM
DET	798	Called By	SRT			
		Is Used By	C81 SLTE	LAMODE STAB	LMODE	MODE
DISK	390	Called By	ROTAN			
		Is Used By	C81 JACOBI	AJACOB MANU	ANAL STAB	ITRIM TRIM
DOGS	180	Called By	ANAL	MNEM	ROTAN	VARI
		Is Used By	C81 JACOBI TRIM	AJACOB MANU	ANAL STAB	ITRIM START
DOROT	1BE8	Called By	ITROT			
		Is Used By	C81 JACOBI TRIM	AJACOB MANU	ANAL ROTAN	ITRIM STAB
		Calls	CLCD	DOTX	RATS	
		Uses	MATRIX	MICE	TABINT	
DOTX	58	Called By	DOROT			
		Is Used By	C81 ITROT STAB	AJACOB JACOBI TRIM	ANAL MANU	ITRIM ROTAN
ELEC	250	Called By	LAMODE	LMODE	MODE	
		Is Used By	C81	LAMODE	LMODE	STAB

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
GUST	7E0	Called By	VARI			
		Is Used By	C81	MANU		
		Calls	RATS			
		Uses	MATRIX			
INIT	1870	Called By	MANU			
		Is Used By	C81			
		Calls	DATE	WRFM		
INRO	B38	Called By	START			
		Is Used By	C81			
		Calls	NOPSIO			
ITRIM	670	Called By	TRIM			
		Is Used By	C81			
		Calls	AJACOB	DAMPER	DATE	JACOBI
			PARA	PDZ1	RATI	RATS
			SOLVE	WRVP1		
		Uses	AJACOB	ANAL	CATS	CLCD
			DATE	DISK	DOGS	DOROT
			DOTX	ITROT	MATRIX	MICE
			OFFTRM	RATS	ROTAN	SWAS1
			TABINT	VIND	WAG1	WRFM
			WROT1	WRVP1		
ITROT	D40	Called By	ROTAN			
		Is Used By	C81	AJACOB	ANAL	ITRIM
			JACOBI	MANU	STAB	TRIM
		Calls	DOROT	VIND		
		Uses	CLCD	DOTX	MATRIX	MICE
			RATS	TABINT		
IVAR	B78	Called By	MNEM	TRIM		
		Is Used By	C81	START		

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
JACOBI	258	Called By	ITRIM	STAB		
		Is Used By	C81	TRIM		
		Calls	AJACOB			
		Uses	ANAL	CATS	CLCD	DISK
			DOGS	DOROT	DOTX	ITROT
			MATRIX	MICE	OFFTRM	RATS
			ROTAN	SWAS1	TABINT	VIND
			WAG1	WRFM	WRVP1	
LAMODE	B40	Called By	STAB			
		Is Used By	C81			
		Calls	COMSOL	ELEC	MODE	NDSLOT
			SRT			
		Uses	DET	ELEC	ROOA	SLTE
			SLTT	SRT		
LMODE	BBO	Called By	STAB			
		Is Used By	C81			
		Calls	COMSOL	ELEC	MODE	NDSLOT
			SRT			
		Uses	DET	ELEC	ROOA	SLTE
			SLTT	SRT		
MANU	1898	Called By	C81			
		Calls	ANAL	INIT	PCG	RATS
			ROTAN	SWAS1	VARI	
		Uses	CATS	CLCD	DATE	DISK
			DOGS	DOROT	DOTX	GUST
			ITROT	MATRIX	MICE	RATS
			ROTAN	SOLVE	TABINT	TILT1
			VIND	WAG1	WRFM	

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
MATRIX	2E0	Called By	CATS	RATS		
		Is Used By	C81	AJACOB	ANAL	DOROT
			GUST	ITRIM	ITROT	JACOBI
			MANU	MNEM	OFFTRM	ROTAN
			STAB	START	TRIM	VARI
MICE	IC8	Called By	ANAL	CLCD	MNEM	
		Is Used By	C81	AJACOB	ANAL	DOROT
			ITRIM	ITROT	JACOBI	MANU
			MNEM	ROTAN	STAB	START
			TRIM			
MNEM	1740	Called By	START			
		Is Used By	C81			
		Calls	CLCD	CON2	DOGS	IVAR
			MICE	NOPSIO	RATS	SWAS1
			TILT1	TINIT	TURN	VIND
			WAG1			
		Uses	MATRIX	MICE	TABINT	
MODE	8F0	Called By	LAMODE	LMODE		
		Is Used By	C81	STAB		
		Calls	ELEC	SLTE	SLTT	
		Uses	DET	ROOA	SRT	
NDSLOT	340	Called By	LAMODE	LMODE		
		Is Used By	C81	STAB		
NOPSIO	328	Called By	INRO	MNEM	STAB	TRIM
		Is Used By	C81	START		

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
OFFTRM	3D0	Called By	AJACOB			
		Is Used By	C81 TRIM	ITRIM	JACOBI	STAB
		Calls	CATS	RATS		
		Uses	MATRIX			
PARA	BC8	Called By	ITRIM			
		Is Used By	C81	TRIM		
		Calls	DATE	WRFM	WROT1	WRVP1
		Uses	DATE			
PCG	248	Called By	MANU			
		Is Used By	C81			
PDZ1	398	Called By	ITRIM	TRIM		
		Is Used By	C81	TRIM		
PPLOT	E80	Called By	C81			
		Calls	C81L	DATE	WROT1	
		Uses	DATE			
RAT1	2A8	Called By	ITRIM			
		Is Used By	C81	TRIM		
RATS	250	Called By	AJACOB ITRIM ROTAN	ANAL MANU STAB	DOROT MNEM VARI	GUST OFFTRM
		Is Used By	C81 ITROT STAB	AJACOB JACOBI START	ANAL MANU TRIM	ITRIM ROTAN VARI
		Calls	MATRIX			

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
READIN	6D8	Called By	START			
		Is Used By	C81			
ROOA	F68	Called By	SRT			
		Is Used By	C81 SLTE	LAMODE STAB	LMODE	MODE
ROTAN	C80	Called By	ANAL	MANU		
		Is Used By	C81 MANU	AJACOB STAB	ITRIM TRIM	JACOBI
		Calls	CATS RATS	DISK WAGI	DOGS	ITROT
		Uses	CLCD MICE	DOROT RATS	DOTX TABINT	MATRIX VIND
SETE	1F8	Called By	STAB			
		Is Used By	C81			
SLTE	1B0	Called By	MODE			
		Is Used By	C81	LAMODE	LMODE	STAB
		Calls	SRT			
		Uses	DET	ROOA		
SLTT	1A0	Called By	MODE			
		Is Used By	C81	LAMODE	LMODE	STAB
SOLVE	408	Called By	ITRIM	VARI		
		Is Used By	C81	MANU	TRIM	
SRT	358	Called By	LAMODE	LMODE	SLTE	
		Is Used By	C81 STAB	LAMODE	LMODE	MODE
		Calls	DET	ROOA		

TABLE I. Continued

Name	Length	Operation	Cross-Reference			
STAB	1498	Called By	C81			
		Calls	AJACOB	ANAL	DATE	JACOBI
			LAMODE	LMODE	NOPSIO	RATS
			SETE	SWASI	WRFM	WRVP1
		Uses	AJACOB	ANAL	CATS	CLCD
			COMSOL	DET	DISK	DOGS
			DOROT	DOTX	ELEC	ITROT
			MATRIX	MICE	MODE	NDSLOT
			OFFTRM	RATS	ROOA	ROTAN
			SLTE	SLTT	SRT	SWAS1
			TABINT	VIND	WAG1	WRFM
			WRVP1			
START	11D8	Called By	C81			
		Calls	CON1	INRO	MNEM	READIN
			WROT1	WRVP1	YFIX	
		Uses	CLCD	CON2	DATE	DOGS
			IVAR	MATRIX	MICE	NOPSIO
			RATS	SWAS1	TABINT	TILT1
			TINIT	TURN	VIND	WAG1
SWAS1	390	Called By	AJACOB	MANU	MNEM	STAB
		Is Used By	C81	ITRIM	JACOBI	STAB
			START	TRIM		
TABINT	5B8	Called By	CLCD			
		Is Used By	C81	AJACOB	ANAL	DOROT
			ITRIM	ITROT	JACOBI	MANU
			MNEM	ROTAN	STAB	START
			TRIM			
TILT1	8A0	Called By	MNEM	VARI		
		Is Used By	C81	MANU	START	
TINIT	2C0	Called By	MNEM			
		Is Used By	C81	START		

TABLE I. Continued						
Name	Length	Operation	Cross-Reference			
TRIM	6F8	Called By	C81			
		Calls	DAMPER	ITRIM	IVAR	NOPSIO
			PDZ1			
		Uses	AJACOB	ANAL	CATS	CLCD
			DAMPER	DATE	DISK	DOGS
			DOROT	DOTX	ITROT	JACOBI
			MATRIX	MICE	OFFTRM	PARA
			PDZ1	RATI	RATS	ROTAN
			SOLVE	SWAS1	TABINT	VIND
			WAG1	WRFM	WROT1	WRVP1
TURN	4D8	Called By	MNEM			
		Is Used By	C81	START		
VARI	17F0	Called By	MANU			
		Is Used By	C81			
		Calls	DOGS	GUST	RATS	SOLVE
			TILT1			
		Uses	MATRIX	RATS		
VIND	3F8	Called By	ITROT	MNEM		
		Is Used By	C81	AJACOB	ANAL	ITRIM
			JACOBI	MANU	ROTAN	STAB
			START	TRIM		
WAG1	C18	Called By	ANAL	MNEM	ROTAN	
		Is Used By	C81	AJACOB	ANAL	ITRIM
			JACOBI	MANU	STAB	START
			TRIM			
WRFM	288	Called By	AJACOB	INIT	PARA	STAB
		Is Used By	C81	ITRIM	JACOBI	MANU
			STAB	TRIM		

TABLE I. Continued

Name	Length	Operation		Cross-Reference		
WROT1	218	Called By	C81 START	CURVET	PARA	PPLOT
		Is Used By	C81	ITRIM	TRIM	
		Calls	DATE			
WRVP1	750	Called By	AJACOB START	ITRIM	PARA	STAB
		Is Used By	C81 TRIM	ITRIM	JACOBI	STAB
YFIX	790	Called By	START			
		Is Used By	C81			

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Bell Helicopter Company Fort Worth, Texas 76101	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A STABILITY AND CONTROL PREDICTION METHOD FOR HELICOPTERS AND STOPPABLE ROTOR AIRCRAFT -- VOLUME III

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

Billy J. Bird

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1970	29	

8a. CONTRACT OR GRANT NO. F33615-69-C-1121 b. PROJECT NO. 8219 c. Task No. 821907 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFFDL-TR-69-123, Volume III

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Flight Dynamics Laboratory Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

This report describes a mathematical model of rotorcraft that may be used to determine characteristics of performance, stability, response, and rotor blade loads. The complexity of the equations used requires the use of a digital computer for efficient solution. This four volume report describes the computer program in detail and illustrates the method of computing rotorcraft characteristics by specific example.

This volume contains aids for the computer programmer. The first and second volumes contain a discussion of the mathematical model and detailed instructions for the users of the program. The fourth volume contains computer generated documentation of the program.

The programming aids are divided into two groups: background material for the programmer just starting to work on this computer program and the detailed explanation of the computer generated documentation which is necessary for any programmer to work effectively on this program.

DD FORM 1 NOV 65 1473

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Helicopter Stability and Control Stoppable Rotor Aircraft Stability and Control V/STOL Aircraft Rotorcraft Simulation						

UNCLASSIFIED
Security Classification